A Cascade Regenerative Receiver

Extreme selectivity—here's a receiver with two *regenerative stages.*

By Bill Young, WD5HOH

A reference to a cascade regenerative receiver can be found on page 78, Fig 47 of *Vacuum Tubes in Wireless Communication* originally published in 1918.[1] The tickler coils in the 1918 circuit are located at or near circuit ground as they are in my cascade regenerative receiver and in the regenerative superheterodyne receiver recently published in *QEX*.[2] I used two circuits that I have used in other receivers that seemed amenable to being connected in cascade. I wanted to try a receiver design that offered the gain and selectivity of a regenerative receiver incorporating two tuned circuits without any of the complications associated with heterodyning. This cascade regenerative receiver tunes from just above 3 MHz to just above 5 MHz. The selectivity, in my opinion, justifies the effort expended to build and operate the extra regenerative stage. One must learn to turn one knob only about half as far as usual and then turn the second knob about the same distance to avoid tuning past stations. In retrospect, I would say that anyone building a cascade regenerative receiver should buy the best vernier drives available.

I'm sure some readers will wonder why I have written an article about a regenerative receiver in 2003 when other experimenters are working on software defined receivers and other advanced concepts. Interest in regenerative receivers hasn't gone away. Every now and then, one appears in print. I have written this article because other experimenters might like to build this or a similar circuit

Nothing in a regenerative receiver should move with respect to anything else except variable capacitor rotors, potentiometer wipers and switch contacts. Even those items can cause problems. Conducting paths should not move or vibrate. Everything must be tied down. Components that exhibit any tendency to move when held by their leads alone should be held down with hot glue. The largest possible wire gage should used. Use lacing cord liberally. Where two or more wires run together for any distance (assuming it's electrically permissible for them to do so) they should be tied together. It need not be pretty; but it cannot move. I have made this receiver as mechanically and electrically stable as I could, and since it's primarily used to tune AM signals with the RF amplifiers at high gain but not oscillating, it's very stable and free of microphonics.

There is a common-source, untuned RF stage between the antenna and the first regenerative RF stage. This serves—as similar stages have for over 80 years—to isolate the regenerative circuits from the antenna, and it presents high impedance to the electrically short wire antenna. The high impedance that the antenna sees makes receiver performance somewhat independent of antenna length. The "gimmick" coupling capacitor allows surprisingly high signal strength on strong signals and, so far, has eliminated any interference from nearby strong stations.

There are two regenerative RF amplifier stages ahead of the bridge detector. Coupling between the first and second stages and the second and third stages is accomplished by 1.8 pF to 10 pF trimmer capacitors. These coupling capacitors should be adjusted for the best possible regeneration control for both stages.

The first regenerative stage design was worked out experimentally with a breadboard circuit. The 560 Ω drain load was determined by temporarily installing a resistance decade box as a drain load and varying the drain load resistance until regeneration occurred.

Each of the two JFET regenerative stages has a tickler winding in series with the drain load at the bottom or "cold" end of the drain load. This circuit was worked out experimentally with "breadboard" receivers, and it results in better, more positive control of regeneration in my opinion. The apparent reason for this is that changing the regeneration controls in this circuit does not change the drain load impedance very much. My article "A Mathematical Model for Regenerative RF Amplifiers,"[3] is a brief discussion of the relationship between regeneration control and drain load impedance.

[1]Notes appear on page 11.

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Also, each tickler winding is positioned directly over the tuned circuit winding. This configuration results in better control of regeneration, but I don't really know why. I've tried the conventional configuration with the tickler winding separated from the tuned circuit winding by a small gap, but regeneration control was rough and erratic that way. I suspect that this behavior is unique to this circuit. Other experimenters apparently get better results with a separated tickler winding and their "leak" detector circuits, but this circuit works best with the tickler winding over the center of the tuned winding. Furthermore, the ratio of tickler turns to tuned-winding turns was determined by trial and error in earlier breadboard circuits, but once determined, seems to remain about the same over a frequency range from below 2 MHz to above 5 MHz, as long as the regeneration control resistances remain about the same.

Each 140 pF tuning capacitor is mounted to the aluminum chassis by its rear mounting lug alone. This makes tuning a little smoother by allowing some motion of the capacitor. The first regenerative stage (second stage) has a "floating rotor" FINE tuning capacitor which consists of a moving aluminum plate or rotor held by a nylon screw and turned by a small vernier drive (see Fig 1). The rotor swings in and out of the space between a grounded plate screwed to the chassis and an insulated plate held at a fixed distance from the grounded plate by nylon screws and spacers. The rotor or moving plate is shaped to have a greater perimeter with less area. The capacitance of the floating rotor capacitor appears to depend more on the "fringe effect" at the edges of the plates and less on the area of the plates. This concept has come from experience with an earlier receiver that incorporated an earlier version of the floating rotor capacitor (see Note 2). The observed change in capacitance is much less than can be accounted for by applying the usual expression for the capacitance of parallel plates with air dielectric. Further experimentation is called for, but the floating rotor capacitor as it exists is very useful when connected in parallel with the tuning

The floating rotor rotates in and out between the fixed metal plates without touching either of them. Capacitance is maximum when the rotor is fully between the fixed plates and minimum when it is as far out as it will go.

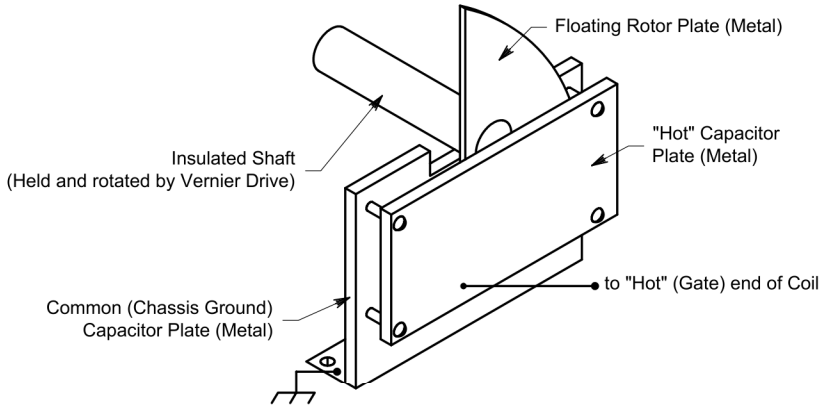

Floating Rotor Plate (Metal)
"Hot" Capacitor Plate (Metal)
Insulated Shaft (Held and rotated by Vernier Drive)
to "Hot" (Gate) end of Coil
Common (Chassis Ground) Capacitor Plate (Metal)

Fig 1—The floating-rotor capacitor.

Tuning and Transformer Resonance

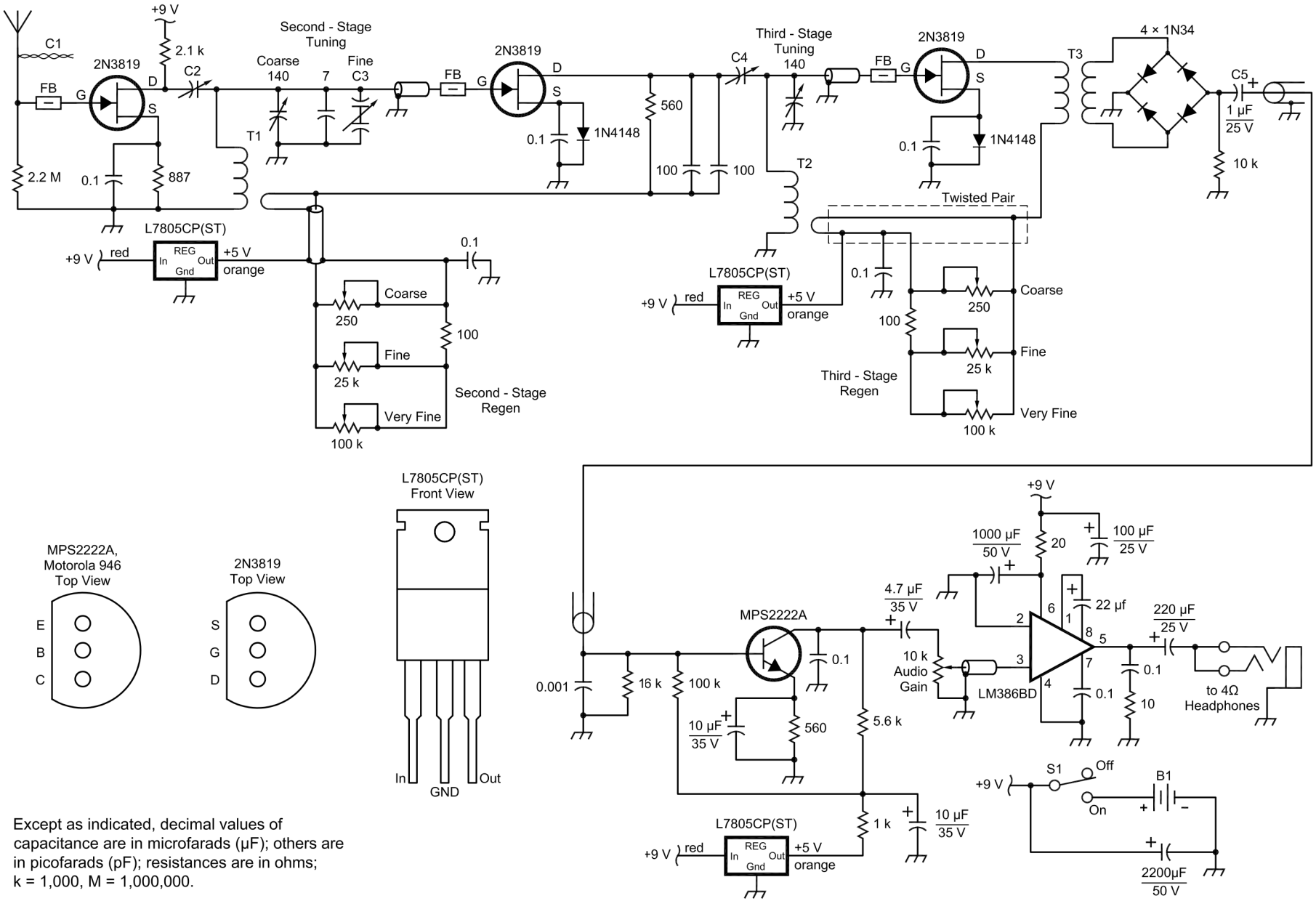
I suspect that self-resonance of a bifilar coupling transformer driving a diode bridge detector results in increased "smoothness" of regeneration control in receivers of this type.

A 90-turn bifilar transformer similar but not identical to T3 exhibited a "dip" or resonance very near 17 MHz. This dip was present with power on and with power off. Regeneration control was smoother near 17 MHz than anywhere else within its tuning range, although the 19-meter band above 15 MHz was almost as good. The 22 meter band just below 14 MHz was noticeably worse, as was the 13 meter band just below 22 MHz. This result, if it's correct seems to agree with the information published in my earlier *QEX* article (see Note 3). Self-resonance would result in increased impedance and improved control. I further suspect that if self-resonance was occurring in the receiver referred to above (not the present cascade regenerative receiver), the only reason the stage wasn't oscillating uncontrollably was the diode-bridge load on the secondary of the bifilar transformer.

The most obvious application of the self-resonant bifilar transformer is in a regenerative intermediate amplifier stage as part of a superheterodyne receiver. The gate tuned circuit and the bifilar transformer could be made resonant at a chosen frequency and left there. Designing such a receiver may not be straightforward, though. Arranging for optimum coupling between a doubly or triply balance mixer and the regenerative IF stage will require some thought.

It may be possible to establish self-resonance of the bifilar transformer at the upper end of the tuning range of a regenerative receiver and switch small, fixed capacitors across the primary of the bifilar transformer to extend resonance across the rest of the tuning range. I'm sure, however, that there's a limit to how far the Q of the bifilar transformer can be increased without loss of regeneration control.

Fig 2—A schematic of the Cascade Regenerative Receiver. The Very Fine regeneration controls were added after the photo in Fig 3 was taken. The MPS2222A stage is an audio preamplifier circuit from the *1992 ARRL Handbook*. Unless otherwise specified, use 1/4 W, 5%-tolerance carbon composition or film resistors. You can contact Mouser at 958 N Main St, Mansfield, TX 76063; tel 817-483-4422; fax 817-483-0931; e-mail sales@mouser.com; Web www.mouser.com.
B1—Rayovac NM1604, 150 mAh 8.4 V (for 9 V applications, rechargeable).
C1—"Gimmick" capacitor, 4 turns of insulated solid hook-up wire.
C2, C5—1.8-10 pF ceramic trimmer capacitor (Mouser 242-1810).
C3—140 pF variable capacitor.
C4—Floating-rotor capacitor, see text and Fig 1.
C5—1 µF 25 V, low leakage capacitor.
FB—Fair-Rite EMI shield bead (Mouser 623-2643000101).
S1—SPST ganged with the fine regeneration pot in the third stage.
T1—Transformer 22 t primary 3/4 inch long on a 7/8 inch PEX form, with a 4 t secondary wound over the primary's cold end. The lead to the potentiometers is RG-174 coax. Shield the transformer by covering it with a small metal food can, such as that for Mandarin oranges.
T2—Transformer 22 t primary 3/4 inch long on a 7/8 inch PEX form, with a 4 t secondary wound over the primary's cold end. The lead to the potentiometers is a twisted pair. Shield the transformer by covering it with a small metal food can, such as that for Mandarin oranges.
T3—Bifilar transformer, 90 t 24 AWG enameled wire twisted, and then wound over two inches on a 3/8 inch diameter PEX form. T3 is mounted inside the aluminum chassis box.



Except as indicated, decimal values of capacitance are in microfarads (µF); others are in picofarads (pF); resistances are in ohms; k = 1,000, M = 1,000,000.

capacitor of a regenerative stage. It enables very accurate tuning of AM signals. This accurate tuning when used together with precise control of regeneration made possible by the combination of COARSE, FINE and VERY FINE regeneration control potentiometers results in improved sensitivity and selectivity. An increment of one small division of the FINE tuning control can result in a noticeable change in signal level, so the FINE tuning control does serve a useful purpose.

Some builders of regenerative receivers advocate a single-point ground. The circuit board for this receiver has a buss wire "fence" around the edge of the board. The "fence" does not form a closed loop. All ground connections are made to this wire which is then connected to a single ground lug held to the aluminum chassis by a machine screw and nut. There are several other connections at some distance from the board made in the same way with a lug and a machine screw. The receiver performs well, so I assume the grounding scheme is adequate.

I have attempted to evaluate potential RF coil form materials by placing them, one at a time, in the field of an RF coil connected to an oscillating RF regenerative amplifier stage. I set the tuning for an audible beat note and then placed a small sample of the material in the field of the coil. I have tried cardboard, glass, wood, PVC, acrylic, PEX (cross-linked polyethylene), the much recommended black-plastic film container and a plastic "pill bottle." Each of these changed the frequency of oscillation substantially, some more than others. Each was suspended in the field of the coil at the end of a length of waxed nylon lacing cord. The length of lacing cord was shown to affect the frequency very little by itself. I decided by a process of repeated comparison that the PEX would be the material of choice. It doesn't crack as easily as acrylic, and it's easier to cut and drill. The two coils are mounted above the chassis deck on square pieces of Vector board, and each coil is enclosed in a cylindrical metal shield can (formerly filled with Mandarin orange slices).

I have been reminded recently that conventional regenerative detectors tend to exhibit capture effect, where a strong signal close in frequency to a weak signal takes over the receiver from the weak signal. That does not appear to happen with this circuit. Strong signals are audible "behind" or "under" weak signals, but there is no capture.

Each of the regenerative RF stages incorporates a silicon 1N4148 diode in the source circuit of the 2N3819 JFET. This idea was suggested in an unpublished private correspondence with Charles Kitchen, N1TEV. It is something he said he had thought of but not tried. I tried it and have been much impressed with the performance it contributes. It makes the receiver much more capable of tuning AM signals below oscillation and somewhat less capable of tuning CW signals above oscillation. This trade off is fine with me. I have been trying to do this for years with partial success. The diode seems to delay the onset of oscillation allowing higher gain below oscillation.

The cascade regenerative receiver was originally constructed as a single board receiver. All of the transistors, diodes and the integrated circuits were mounted on a single perforated board. The board is mounted about an inch below the underside of the chassis deck on six nylon standoff insulators. I have now added a single MPS2222A junction-transistor audio preamplifier taken from page 28-5 of the *1992 ARRL Handbook* and mounted on a small board adjacent to the main board. I removed the transformer-coupled 2N3819 audio amplifier circuit originally placed between the bridge detector and the LM386 because it contributed too little gain and caused an annoying audible "quench" frequency. The MPS2222A stage works well, and I'm confident that the receiver can be built as a single-board receiver. There's plenty of room on the main board for the MPS2222A stage.

The LM386 final audio stage is conventional except possibly for the 2200 µF capacitor across the 9 V dc supply, which is necessary to prevent "motorboating" or instability.

The cascade regenerative receiver can be operated as follows: Start by setting both main tuning capacitors to about 80 on their logging scales. With FINE and VERY FINE regeneration controls fully clockwise adjust the COARSE control so that the stage is just oscillating. Do this at reduced audio gain. Then turn the FINE control counter-clockwise so that oscillation just stops and then go back clockwise with the FINE control until the stage is just oscillating. Now, turn the VERY FINE control counter-clockwise until the stage stops oscillating, and use the VERY FINE control to adjust stage gain just short of oscillation. Turn the AUDIO GAIN pot clockwise to increase audio gain. This procedure can be followed with each of the two regenerative RF stages. Some careful tuning will help as these adjustments are made. It may be necessary to repeat some of the adjustments until the receiver has stabilized after several minutes, but it will stabilize and can be maintained at high gain for extended listening.

Now, turn each of the two main tuning knobs to discover which one causes oscillation to stop when tuned in the direction you want to tune. Oscillation can then be started again by turning the other main tuning knob in the same direction. Proceed to tune incrementally this way (turning one main tuning knob, then, the other) until an interesting signal is heard.

When you have acquired a signal adjust the FINE regeneration controls appropriately depending on what you're trying to receive (AM, CW, RTTY and so on). For AM signals, back

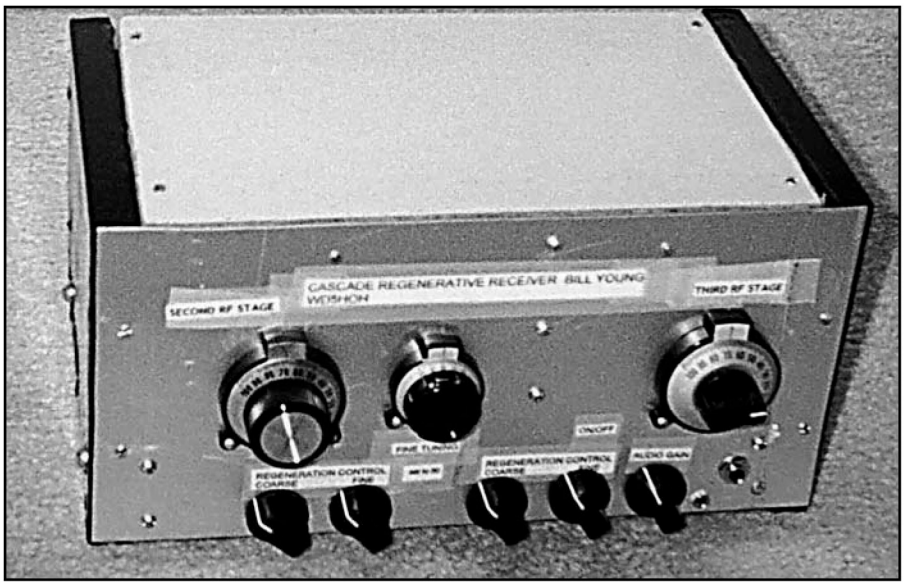


Fig 3—Front view of receiver.

off the FINE controls until you have a clear AM signal, and then advance each VERY FINE control in turn for maximum signal level. Work with the two FINE regeneration controls and the VERY FINE tuning control to tune exactly to the center of an AM signal at maximum gain. Increasing the VERY FINE regeneration controls beyond a certain point results in distortion and the onset of "fringe howl." It's easy with this selective receiver to tune past a signal without hearing it.

If you have reached the conclusion that this receiver is laborious to tune, you're right. It is. Now you know one reason why the superhet came to be dominant. If you need to switch quickly and repeatedly between several air-to-ground frequencies, you really can't do it with a receiver like this. That's one of the things a crystal controlled superhet could do well.

On the other hand it's fun to tune in a weak signal, peak both RF stages to that signal and then pull it up out of the "mud" using the two VERY FINE regeneration controls without either stage going into oscillation. A disadvantage of this receiver is the presence of the "skirts" of powerful shortwave broadcast signals tens of kilohertz away from their carrier frequency. However, most of the weaker signals will increase in signal strength as they are tuned in and as the regeneration is increased enough to overcome this interference. At my location, this has been a problem only around 5 MHz.

There are a couple of things about the performance of this receiver that are puzzling:

1. Even if both regenerative stages are oscillating and are not tuned to the same frequency there is no audible heterodyne.
2. There is some interaction between the two regenerative RF stages at high gain even though their coils are shielded and they are both voltage regulated.

This receiver was powered at first by disposable 9 V alkaline batteries, but I am now using a Rayovac NM 1604 NiMH rechargeable battery with good results. This battery powers this receiver for about three hours between charges. The internal impedance is low enough for good performance until the battery voltage drops off the "plateau" and needs recharging. The transition from plateau to a weak battery is abrupt. It suddenly becomes necessary to increase regeneration to maintain gain, but gain decays faster than regeneration is increased. At this point switch the receiver off, and recharge the battery.

You will probably notice that the ON/OFF switch is built into one of the FINE regeneration controls rather than the audio gain potentiometer as is usual. This choice is a result of parts availability only. If you can find a 10 kΩ pot with a switch, use it.

Bill is retired following a 36-year career as a project engineer and manager with NASA in the biomedical-hardware area. He was first licensed as KN5DNM in about 1953 and has been WD5HOH (General class) since about 1980. He holds a BSEE from the University of Texas (1961) and an MS in environmental management from the University of Houston (1981) at Clear Lake.

Notes

[1]E. Bucher, *Vacuum Tubes in Wireless Communication,* (New York: Wireless Press, 1918).

[2]B. Young, WD5HOH, "A Homebrew Regenerative Superheterodyne Receiver," *QEX*, May/Jun 2002, pp 26-35.

[3]W. Young, WD5HOH, "A Mathematical Model for Regenerative RF Amplifiers," Jul/Aug 2001, pp 53-54.

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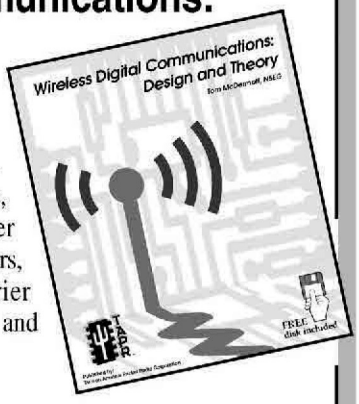

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